CHAPTER 9

Main Transverse Bulkheads

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Main Transverse Bulkheads

Introduction

1 Main transverse bulkheads are fitted in ships to fulfil a number of functions. Under normal operation these bulkheads serve to maintain the form of the hull, resisting lateral loads due to sea pressure, berthing and docking, as well as resisting shear and torsional deflections of the hull. At the same time they divide the ship into main compartments which are frequently devoted to different functions, protecting, for example, spaces for electronic equipment from spaces containing heavy machinery. Another important function of bulkheads is to support large in-plane loads due to heavy equipment or weapon recoil, or at the ends of superstructures as described in Chapter 8. Additionally, under damaged conditions, the function of main bulkheads is to restrict the extent of fire, flooding or blast.

2 Although the maintenance of form is an important function, it will only rarely affect the scantlings of a bulkhead, and so this chapter will concentrate on methods for designing bulkheads to withstand lateral pressure and in-plane loads.

3 Methods for estimation of in-plane loads due to equipment and weapons are given in Chapter 4 and at superstructure ends in Chapter 8. Lateral loads due to flooding damage should be derived from the hydrostatic pressure from an envelope of most probable damaged waterline. Design pressures for the forwardmost bulkhead (the 'collision bulkhead') must also be high enough to encompass the hydrodynamic loads imposed by the forward speed of the ship. Whilst it is seldom feasible to design against pressures associated with full speed of a frigate or destroyer, it will normally be possible to allow for a forward speed of 12 to 15 knots without undue weight penalty. It will be sufficient in this case to use the stagnation pressure appropriate to the required speed as a static design pressure.

4 Parts of main transverse bulkheads may also constitute tank boundaries and as such they will be subject to constant hydrostatic pressure. The design load in these cases can be deduced from the head appropriate to the height of the tank vent, with margins for error as discussed below.

5 Generally, plated structures are most efficient when stiffened in the shortest direction and bulkheads are no exception. This almost invariably means that bulkheads will be stiffened vertically, as even when there are no intermediate decks the beam is usually greater than the depth. Locally, however, for resistance to explosive loading, stiffeners may run in other directions and this variation is discussed later (paragraph 42 et seq). For the principal loads the design methods proposed in this chapter will assume unidirectional vertical stiffening; should orthogo-

nal stiffening be required for any reason, the bulkhead should be designed as a grillage as described in Chapter 10.

6 In merchant ships it is not uncommon to use corrugated bulkheads, although these are rare in warships as they take up extra space and are difficult to integrate with decks and other structure. The design of corrugated bulkheads will not therefore be discussed here, but if guidance is required it may be found in Caldwell (1955), Basu and Chapman (1967) and Caldwell (1983).

7 A final point to be noted is that bulkheads must continue to function adequately after explosive attack, especially in maintaining watertight boundaries. This requirement imposes some restrictions on the arrangement of plate and stiffeners around the periphery below the waterline to ensure that premature tearing and loss of watertightness does not occur, and the details are discussed below. Connections around the boundary must also be in accordance with the design specification.

Design Against Lateral Loads

8 The scantlings of major transverse bulkheads are usually determined by the requirement to resist lateral pressures. Such pressures, as described above, may be caused by accidental flooding, hydrostatic or dynamic pressures in tanks, water and airtightness tests or accidental missile ignition. Because lateral pressures have such a large influence on the structure of bulkheads it is best to design the structure taking account of lateral loads before checking the resistance to other loads.

9 The first task is to select an arrangement for the stiffening and plating. Since bulkheads are usually divided by decks into a number of wide short rectangular panels the stiffening will be best arranged vertically as stated in paragraph 5. Additionally, as discussed in more detail below under resistance to explosive loading, the stiffeners must be arranged so that they end on longitudinals in the hull bottom, but even where a bulkhead does not extend to the bottom it is desirable that bulkhead stiffeners all end on either deck longitudinal stiffeners or other stiff structure so that a hard spot which creates a stress concentration and, potentially, a fatigue failure point, is not introduced. If the layout of deck and bottom stiffeners leaves any choice in the positioning of bulkhead stiffeners it should be remembered that close spacing leads to thinner plating and lighter weight, but less robustness and greater sensitivity to corrosion. More widely spaced stiffeners and thicker plate will be heavier but easier to build and maintain, with less welding distortion and associated rework when fitting decks and items of equipment to the bulkheads. Thicker plating also contributes to ballistic and blast protection and hence improves survivability.

10 When the arrangement of stiffeners has been determined it is next necessary to decide the scantlings and for this either elastic or plastic design methods may be used. Plastic methods relate an extreme design load to the ultimate collapse condition of the structure and may save some weight provided that the normal working loads are low and that a fairly flexible structure is acceptable. If normal working loads are relatively high, for example in tanks, or if it is important to limit deflections, then elastic methods must be used.

Plastic Design Methods

11 These methods are appropriate to bulkheads where the critical design load occurs only occasionally under accidental conditions, for example following action or collision damage, and when some yielding and permanent set of the structure is acceptable. If there is any doubt as to the critical design condition then elastic design methods should be applied. Note that plastic design is not appropriate for materials which do not have an appreciable elongation to failure, such as fibre reinforced plastic.

12 The design pressure will be determined from an envelope of the likely damaged waterline; if these is doubt as to the damaged water head then the bulkhead should be assumed flooded up to the upper deck. Alternatively, if the accident condition involves ignition of a missile motor in a magazine, the resultant pressure will depend on the rate of burn, the volume of the compartment and the existence of any 'blow-off plates' (plates that blow out of the structure as a given pressure so as to limit pressure damage). If the blow-off plate design pressure is known then the structure should be designed with a small margin (say 10%) above to allow for uncertainties and dynamic effects; otherwise the missile and magazine designers should be consulted on the design pressure to be used.

13 As discussed above, it will be assumed in the following paragraphs that the bulkhead is unidirectionally stiffened in the short direction. The first requirement is then to calculate the plate thickness, which should be based on an acceptable permanent set between stiffeners. No absolute criterion can be laid down as the allowable set must be based on circumstances, for example on whether unacceptable damage can occur to essential equipment attached to the bulkhead. In the absence of any other criterion a figure of about b/75 is reasonable for steel, where b is the stiffener spacing. At this level it is very unlikely that any local tearing will occur unless there are particularly bad structural details.

14 Research work undertaken by Clarkson (1956, 1960) showed that for practical structures the ultimate strength is reached at approximately half the ideal material strain to failure, and using membrane theory it can be shown that this relates to a deflection value of about b/7 for mild steel which has a strain to failure of 17%. Consequently, the value of b/75 suggested above allows a margin of about 10 over the ultimate strength, which gives some guide for the choice of other acceptable deflection values. Higher values than b/75 may be acceptable in circumstances where the deformation of the plating is closely matched to the deformation of stiffeners so that the risk of rupture is minimised.

15 The references also give deflection curves for long plates (strictly at an aspect ratio of 3, but the difference between that and infinite plates is not significant) which are reproduced on data sheets 18.45 to 18.48. These allow the normalised pressure and allowable deflection to be used to estimate an acceptable value of plate slenderness ratio ß and hence thickness if b is known. For lower aspect ratios, curves are available in the references for specific types of steel but these are somewhat out of date and relate to steels not now recommended. It is unlikely that aspect ratios of plate less than 3 will apply for bulkheads, but in that event the use of the data sheets in Chapter 18 is conservative.

16 To the plate thickness derived in this way must be added the allowance for the rolling tolerance as described in Chapter 5 and an allowance for corrosion if the bulkhead forms part of a tank or wet space where significant unrepaired corrosion may be expected during the ship's life. If no better information is available a corrosion margin of 0.5 mm is recommended. The thickness now reached must be rounded up to the nearest available plate thickness in the material concerned.

17 The next stage is to size the stiffeners, which are designed using three plastic hinge collapse theory. Calculate the maximum applied bending moment using simple beam theory, assuming that the pressure is uniformly distributed over the full plate span between stiffeners and horizontal supporting structure and equal to the pressure at mid-height of the bulkhead (this assumption is only about 3% in error from the real triangular pressure distribution). The assumption of pinned or clamped ends will depend on whether the pressure is applied to the adjacent bay of bulkhead (clamped) or not (pinned); if in doubt assume the stiffener to be clamped. If the bulkhead is not of constant height, for example if it abuts the ship's outer bottom, then the calculation should be carried out for the longest stiffener, unless it is intended to design and size each stiffener independently.

18 The plastic hinge moment (M_P) for the stiffener and associated plate is calculated as follows from equation 9.1 et seq; note that an effective breadth of plate of 30t is recommended in this instance, as less plate is effective during plastic than during elastic deformation.

$$M_p = \sigma_y S \tag{9.1}$$

where σ_y is the material yield stress and S is the plastic section modulus given by

$$S = S_f + S_w + S_p \tag{9.2}$$

and S_f, S_w and S_P are the contributions from the stiffener flange, web and plate respectively. These may be found for a Tee section as indicated in Table 9.1, the two cases referred to being (a) when the effective area of the plate (A_p) exceeds that of the stiffener ($A_f + A_w$) or (b) when $A_p < A_f + A_w$ where A_f and A_w are the cross sectional areas of the stiffener flange and web respectively.

TABLE 9.1
Calculation of Plastic Section Modulus for Tee Section

	Case (a)	Case (b)
S_f	$A_f\,(d + g + t_f/2)$	$A_f\,(D - g + t_f/2)$
S_w	$A_w\,(d/2 + g)$	$\Psi_2 A_w d$
S_p	$\Psi_2 A_p t$	$A_p\,(g + t/2)$
Ψ_1	$(A_p - A_w - A_f)/2A_p$	$(A_w + A_f - A_p)/2A_w$
Ψ_2	$\Psi_1{}^2 - \Psi_1 + 0.5$	$\Psi_1{}^2 - \Psi_1 + 0.5$
g	$\Psi_1 t$	$\Psi_1 d$
d	height of stiffener web	
t	plate thickness	
t_f	stiffener flange thickness	

19 These expressions apply strictly to materials having a well defined yield stress; for other materials, however, it is adequate to use the 0.1% or 0.2% proof stress (whichever is quoted) in place of the yield stress.

20 When a shear force Q is present in the stiffener web at the same point as the maximum bending moment, as it will be if the stiffener is assumed to be clamped at the ends, then the combined load must be taken into account. This done by reducing the *web* cross sectional area to be used in *Table 9.1* to an effective area qdt_w where q is given by

$$q = \sqrt{\{1 - 3\,(Q/dt_w\sigma_y)^2\}} \qquad (9.3)$$

and t_w is the web thickness. It should be noted that if the shear force is greater than $0.58\ dt_w\sigma_y$ then the stiffener will fail due to shear yield without any application of bending moment. The shear force is calculated simply by dividing the total pressure force on the single span of plating by 2 for the two stiffener ends.

21 To allow for uncertainties a load factor of 1.5 between the applied bending moment and the plastic hinge moment (modified if necessary for shear) is recommended. At the same time the *average* shear stress, assuming all the load is concentrated in the stiffener webs, should not exceed the nominal value of shear yield, that is Q must be less than $0.5\ dt_w\sigma_y$. It is also necessary to ensure that the critical *elastic* tripping stress under lateral load is not exceeded as described for hull structure in Chapter 7 (paragraph 25). In this case it is sufficient, however, to ensure that the critical stress derived from equation 7.10 is more than 3 times the material yield stress. If margins against tripping are inadequate, the most effective way to increase the critical stress is to introduce flat bar intercostal members between the stiffeners thus reducing the effective span. Small 'tripping brackets' supporting the web are not particularly effective because they do not inhibit plate bending sufficiently.

Elastic Design Methods

22 Elastic methods must be used when the bulkhead is subjected to pressure during its normal operational life, or when it is subjected to test pressures. Additionally, such methods should be used if there is a risk of a relatively frequent accident condition existing such as over pressurisation, or indeed in any other case of doubt. In all these conditions it is important that the structure remains elastic and that no permanent deformation is caused in service.

23 In the above cases the design pressure will be apparent from the operational state, for example the vent head height for a tank or the test pressure for a bulkhead of a compartment which is subject to air or water testing. In the case of tanks, however, more thought needs to be given to the design pressure which should include allowances for the dynamic effects of ship motion on the liquid in the tank, otherwise known as 'sloshing'. This may be accounted for by calculating the hydrostatic pressures due to a pitch angle of 10° or a roll angle of 30°, whichever is the greater. The static head should also take account of all possible modes of operation of the filling and liquid transfer systems giving consideration to the rate of filling and the size of the vent.

24 Once again the structure is assumed to be stiffened only in the vertical direction and the first requirement is to estimate the plate thickness. This is done by calculating the maximum stress in an infinitely long plate panel with clamped edges (free to pull in) using simple plate theory as presented by, for example, Timoshenko 'Theory of Plates and Shells', or Roark 'Formulae for Stress and Strain'. As plate yield is not especially significant it will be sufficient to ensure that the stress so derived is not more than the yield stress, unless the design load is applied frequently, for example in tanks, in which case a margin will be needed to allow for fatigue (see Chapter 13); a figure of 1.2 will probably be adequate to begin with until more detail is available for fatigue calculations. If the load is applied only occasionally then it may be acceptable to allow a small permanent set in the plate while still designing the stiffeners elastically. In this case the method of paragraph 15 above should be used but a deflection of, say, b/200 is more likely to be appropriate.

25 When the basic thickness has been derived it will be necessary to add rolling and corrosion margins as described in paragraph 16 and then to round to the nearest available plate thickness above. Whatever the result of this calculation, due to the requirement for resistance to the normal rigours of a ship's life, it is recommended that plate of thickness less than 5 mm is not used.

26 The stiffeners are sized using simple beam theory making appropriate assumptions for pinned or clamped ends as discussed for plastic design (paragraph 17). However, proper allowance must now be made for the variation of pressure along the length of the stiffener, with the load per unit length being found from the actual pressure head multiplied by the span between stiffeners. The effective breadth of plate may be taken as whichever is the least of b/2 or 40t. The load factor to be allowed will depend on the certainty with which the load is known but generally a factor of 1.1 to 1.2 will be sufficient provided that there are no large changes of stiffness between stiffeners in adjacent sections of bulkhead, and that the bulkhead connections are well designed as discussed in paragraph 51. If these conditions are not met then the load factor should be increased, perhaps to as much as 1.5.

27 The same requirements for shear stress and critical tripping stress should be applied as for plastic design above (paragraph 21). Additionally, in the case of tank bulkheads, to minimise the risk of fatigue failure, seam welds should be positioned as far as possible in regions of low stress, and the number of bulkhead penetrations must be kept to a minimum.

Design Against In-Plane Loads

Distributed Loads

28 As well as lateral loads there also a number of causes of in-plane loading on bulkheads as discussed above. These may be either distributed along all or part of the periphery or concentrated as point loads. Distributed loads are mainly due to lateral loads on other elements of the structure, for example wave action on the hull causes racking and torsion which leads to loads on bulkheads to maintain the form of the ship, while sea pressure on the hull is directly resisted by bulkheads which are much stiffer in-plane than transverse frames. Similarly, vertical loads on decks are transmitted in-plane to bulkheads and the ship's side. None of these are especially significant for the design of bulkheads, leading to stresses only of the order of 20 to 30 MPa. However, as

bulkheads are generally stiffened only in one direction loads in the orthogonal direction, usually those from the ship's sides, are not well supported against buckling failure. If therefore the bulkhead b/t ratio is greater than 60, in-plane buckling calculations should be carried out as described for decks in Chapter 7, but noting that the plate element is loaded across the short direction and so the data sheets in Chapter 18 will not be applicable; the design curves given by Smith et al (1988) will need to be used. Lateral pressure on the hull is reacted partly by decks and frames, not only by bulkheads, so the line load on the bulkhead should be taken as the hydrostatic pressure given in Chapter 3, spread over 3 frame spaces (one and a half either side) or, if it is less, half the distance to the next bulkhead on either side. These are severe loads, but because of the uncertainty of the derivation and of the calculation, a load factor of 1.2 is recommended.

Concentrated Loads

29 Bulkheads are very stiff in-plane, particularly in the stiffened direction, but large concentrated loads, for example due to docking or weapon recoil, may necessitate additional stiffening over a local area. Diffusion of concentrated loads into structure is a difficult phenomenon to analyse and so any design method will require sweeping assumptions. The procedure given below therefore will lead to a reasonable first attempt at scantlings, but the result must always be checked using more sophisticated analysis (usually a finite element method) if the load is particularly large or alignment of the equipment or bulkhead is essential under extreme conditions.

30 A means of estimating loads due to docking is given in Chapter 4, but all the docking load is not transmitted into the bulkheads, and indeed to assume it to be so would be unduly conservative. The proportion of docking load taken by bulkheads rather than through the side frames into the shell depends on the stiffness of the keel and bottom structure in relation to the dock block stiffness. Measurements taken by the Naval Construction Research Establishment (now the Defence Research Agency, Dunfermline) in the 1950s suggest that about one third of the load is taken by bulkheads on small ships with light bottom structure, reducing to a fifth or less for large double bottomed ships. It is, therefore, reasonable to use the method of Chapter 4 to estimate the load per unit length at each bulkhead and then to spread it over one third of the bulkhead spacing for single bottomed hulls and one fifth for double bottomed hulls. The only exception to this will be the bulkhead at the cut-up where the load per unit length should be calculated from equation 4.5 and spread over a length from the transom to a point one fifth of the bulkhead spacing forward of the cut-up bulkhead.

31 Where heavy items of equipment such as winches or gun mountings are sited over bulkheads (as they should always be) the full load, as derived from the methods of Chapter 4, should be used for bulkhead design, including allowances for inertial loads due to ship motion and for gun recoil loads (resolved into the plane of the bulkhead). This is because these loads are very localised and the bulkhead, being much stiffer in plane than the deck structure which will be loaded in bending, will inevitably take the majority of the load. If, however, the item is sited close to the ship's side, some load will be carried into the side and the same design philosophy should then be applied to the local scantlings as to the bulkhead.

32 In designing the bulkhead, large stiffeners will need to be placed at each point of application of the load, for example above the keel or below the main fixing points of equipments. The purpose of these stiffeners is to carry the whole load at the point of application and to distribute it progressively into the plating, as the same time as taking bending moments due to the inevitable eccentricity of the load in relation to the neutral axis of the combination of stiffener and plate. The stiffener will always carry stress greater than or equal to that in the plate due to shear lag effects and initial distortions, so that the main part of the procedure involves sizing the stiffener.

33 The following method is derived from BS5400 Part 3, the 'Code of Practice for Design of Steel Bridges', where it is assumed that a bulkhead is similar to a box girder bridge diaphragm. However, the method here is modified and simplified to take account of the unidirectional arrangement of stiffeners and of the different means of reacting concentrated loads on a bulkhead.

34 The stiffener and its associated plating are initially sized using the direct and bending stresses applied. First calculate the direct stress immediately under the load, taking the actual load specified in Chapter 4 over an area consisting of the stiffener and a breadth of plate equal to the width of the item which is applying the load, for example the breadth of the flat keel for dock block loading. If the width of the load applicator is not known, use a width equal to that of the stiffener flange. On top of the direct stress a compressive bending stress must be added which has two components, the first is the effect of any eccentricity between the line of the applied load and the neutral axis of the stiffener plate combination and the second is the applied moment (if any) due to the position of the centre of gravity of the item relative to its mounting points. It is recommended that stiffener be then chosen so that the total stress derived using simple beam theory is not more than 75% of the yield stress.

35 Having done this check immediately below the load, it is necessary to repeat the calculation at a number of points further away from the load until it is clear that the safety margins are increasing. The load should be assumed to diffuse outwards over a triangular area 40° either side of the vertical. All the structure may be taken to be effective for direct stresses, but an effective plating breadth of 25t should be used for bending stresses. The same checks as in paragraph 34 are to be completed aiming for the same criteria. It may be that a smaller stiffener is acceptable further away from the loading point, in which case it is permissible to taper the scantlings down if so wished, using the rule given in paragraph 51d.

36 It is next necessary to undertake a check on buckling, and to this end the critical buckling stress (σ_c) of the stiffener plate combination must be found from data sheet 18.10 assuming average imperfections. The column slenderness ratio λ is found using the whole unsupported span of stiffener (if the span is too great, for example if the bulkhead is between two machinery spaces, then it will be necessary to insert a deep horizontal stiffening member, with a bending stiffness at least 5 times that of the vertical stiffener), and the plate slenderness ratio β should use the full stiffener spacing b. The value of σ_c derived must then satisfy the criterion

$$\sigma_{ad}/\sigma_c + \sigma_{ab}/\sigma_y \leqslant 0.75 \qquad (9.4)$$

where σ_{ad} and σ_{ab} are the direct and bending applied compressive stresses derived in paragraph 35 above for the effective breadth of 25t, and σ_y is the yield stress. The value of 0.75, here and in paragraph 34, is made up of partial safety factors as described in BS5400 Part 3.

37 The only check that needs to be made on the plating is for local buckling and here it is sufficient to ensure that the elastic buckling criterion for an infinite plate is satisfied, that is

$$F/(A_s + 2bt) < 3.62\ E\ (t/b)^2 \qquad (9.5)$$

where F is the applied force, A_s is the stiffener area and b and t are the stiffener spacing and plate thickness respectively. The factor 2bt is used on the left side of the equation as the worst case when the load has diffused out of one stiffener either side of the stiffener under the load.

38 A remaining check needs to be carried out to ensure that the other stiffeners on the bulkhead are sufficiently large to withstand shear buckling. The check is done in the same way as for the ship's side in Chapter 7 (equation 7.13) but the stress should be taken as the average over a vertical section through the plate between horizontal supporting structure (the same span a as used for the calculation of λ in paragraph 36), that is the stress is F/2at, where the factor of 2 in the expression allows for symmetry about the line of the load, and edges should be assumed pinned, not clamped.

39 In detailing the bulkhead connections it is important to note that any bending moments discovered in the calculation in paragraph 34 will also be applied to the attached deck structure. Consequently, the deck stiffeners must also be sized locally to take the bending moment (it may at the same time be possible to reduce the bulkhead scantlings, but it must not be forgotten that the bulkhead is taking *all* the *direct* load) and bracketed connections may be appropriate.

Loads Under Superstructure

40 The only other in-plane loads which may govern the scantlings of a bulkhead are those under the ends of a superstructure, or indeed those on any bulkhead under a superstructure. An initial means of conservatively estimating these forces is given in Chapter 8, paragraphs 45 and 72, although the only accurate means will be by finite element analysis, also discussed in Chapter 8. Once the loads are known (or estimated) the strength of the bulkhead may be checked as if it were a deck in compression, as described in paragraph 28 and Chapter 7. However, particular care needs to be taken when the superstructure is inset from the ship's side as high stresses will be developed at the end corners and in the bulkheads below. It will usually be necessary to fit thick inserts into the bulkhead plating in these areas but guidance on the thickness and extend can only be found from a study of previous successful designs, followed by analysis using finite elements as stated above.

41 For a transverse bulkhead in the hull, directly below a block of superstructure, and which is not continued up into the superstructure (bad practice anyway), the forces on the bulkhead will be concentrated at two points and will have to be treated as concentrated loads, with large vertical supporting stiffeners, as discussed in paragraphs 32 et seq.

Resistance to Explosive Loading

42 If a ship undergoes explosive attack from either conventional or nuclear weapons, the bulkheads are subjected to a type of loading for which it is difficult to allow in design calculations. Wartime experience, and subsequent tests on target ships, revealed many cases where serious damage was caused to bulkheads because they were not strong enough to withstand explosive loading. If such damage causes rupture of the bulkhead plating then the bulkhead can no longer fulfil its primary function of containment and the resulting more extensive flooding may well endanger the ship. There are two facets of the problem, internal air blast and underwater shock, and it is the latter that then posed the greater risk. However, modern missiles with large warheads cause significant internal blast, and bulkheads should have some resistance to both forms of attack.

Underwater Shock

43 As a result of this experience, research was undertaken in the 1950s at the Naval Construction Research Establishment (now the Defence Research Agency, Dunfermline) to study the mechanism of explosive damage and to propose ways in which the construction of bulkheads might be improved to resist explosive attack. Full scale explosion trials were conducted on a number of target ships, and these led to a clearer understanding of how explosive loading is applied to bulkheads. Various alternative ways of resisting the loading were then considered and it was concluded that the most effective solution is to strengthen and stiffen bulkheads to withstand whatever loads could be transmitted from the adjacent longitudinal structure. A transverse bulkhead in another target ship was therefore strengthened in the manner that had been concluded to be best, and subjected to further attack. The marked improvement in performance compared with earlier designs showed that the proposed modifications did indeed give the expected greater explosive resistance.

44 It should be noted, however, that the research described above was primarily concerned with transverse bulkheads in single hulled ships, and the recommendations which follow refer to bulkheads of this type. Nevertheless, it is considered that the philosophy underlying these proposals is applicable to ships with double bottoms and also to longitudinal bulkheads.

45 Explosion pressures acting on the bottom and sides of a ship tend to distort the cross section of the hull, and this distortion is resisted to a large extent by the transverse bulkheads. In thus preserving the shape of the hull a bulkhead is subjected to loads applied to its edges in the plane of the bulkhead. Thus, wherever a longitudinal member passes through a bulkhead, any external pressure tending to force the longitudinal inwards will produce a reaction in the bulkhead. It is these reaction forces which are the primary cause of explosion damage to a bulkhead and it is the object of the recommendations given below to ensure that a bulkhead will be matched in strength to the adjacent longitudinal structure.

46 It follows that any measures which can be taken to reduce the loads applied to bulkheads by longitudinal structure will lead to a reduction in bulkhead scantlings. The magnitudes and distribution of edge loads on a bulkhead clearly depend on the arrangement of hull structure between bulkheads, and to reduce these edge loads the following points should be noted:

a. The sizes of longitudinal members passing through, or ending on, bulkheads should be as small as possible, consistent with their having adequate strength and stiffness for their other functions. In machinery spaces consideration should be given to supporting machinery on transverse bearers. Where deep continuous longitudinal bearers are indispensable, or in way of the vertical keel, special attention must be paid to the design of the bulkhead in way of these members, in particular as described in paragraph 51c. below.

b. As far as possible hull longitudinals should be of uniform size, and alternate large and small sizes should be especially avoided, since they give rise to high shear forces in the bulkhead and so can cause early rupture of the bulkhead plating.

c. Transverse framing should be designed to avoid any features which weaken the resistance of the frames to explosive attack. For example, at the turn of bilge or near the keel where high shear stresses may occur, the presence of lightening or access holes greatly reduces the shear strength of the frame webs, and such holes should only be cut if they are essential at that point. Similarly, near the turn of bilge many cases occurred during target trials where early buckling of a frame led to its complete collapse, and so special attention needs to be paid to the stability of frame webs in this area.

Internal Blast

47 There is currently little information available on the design of bulkheads to withstand internal blast effects. Generally a bulkhead will fail under blast loading by rupturing at a stress concentration or weld, and so attention to good detail is essential.

48 Double skin bulkheads, either constructed in situ by welding plating to the flanges of the stiffeners of the main bulkhead structure or, more efficiently, by buying in commercially available sandwich materials, are likely to show considerable improvements in blast resistance. The double skin structure, as well as providing a second surface to contain the blast, has much more evenly distributed stiffness and rupture is, therefore, less likely. However, particular attention must then be paid to the peripheral welded connections, and it may be desirable to fit special rolled sections with a flange in the hull and with webs supporting the bulkhead, if the full blast resistance is to be obtained.

Bulkhead Plating

49 Plate thicknesses over the main part of the bulkhead should be determined to ensure adequate strength under normal or accidental loads as described earlier in this chapter. However, at the edges of the bulkhead where it meets the bottom and side of the ship, the bulkhead plating should be thickened to give increased strength and stability under explosive loading. The depth of this thickened strip (measured normal to the hull plating) should be not less than 1.5 times the spacing of the longitudinals (excluding occasional deep members) at the point considered. A possible arrangement of strakes of plating is shown in *Figure 9.1*. The thickness of this strip should be not less than all of the following:

a. 80% of the thickness of the adjacent shell plating.

b. The thickness of the web of the nearest longitudinal hull stiffener.

c. 6.5 mm.

The normal corrosion allowance should be added to the thickness obtained, as described in Chapter 5.

50 This thickened outer strip, being vital to the strength of the bulkhead during explosive attack is as important to ship strength as the hull sheer strake or the deck stringer plate. Holes should not be cut in it except where absolutely unavoidable, in which case the bulkhead plating must be fully compensated for the material removed in such a way that its strength and stability are not impaired.

Bulkhead Stiffening

51 The normal arrangement of vertical stiffening previously described should be continued through to the hull, but subject to the following requirements:

a. Wherever hull longitudinals pass through, or end on, a bulkhead, there must be a bulkhead stiffener connected to each hull longitudinal, and vice versa. This is most

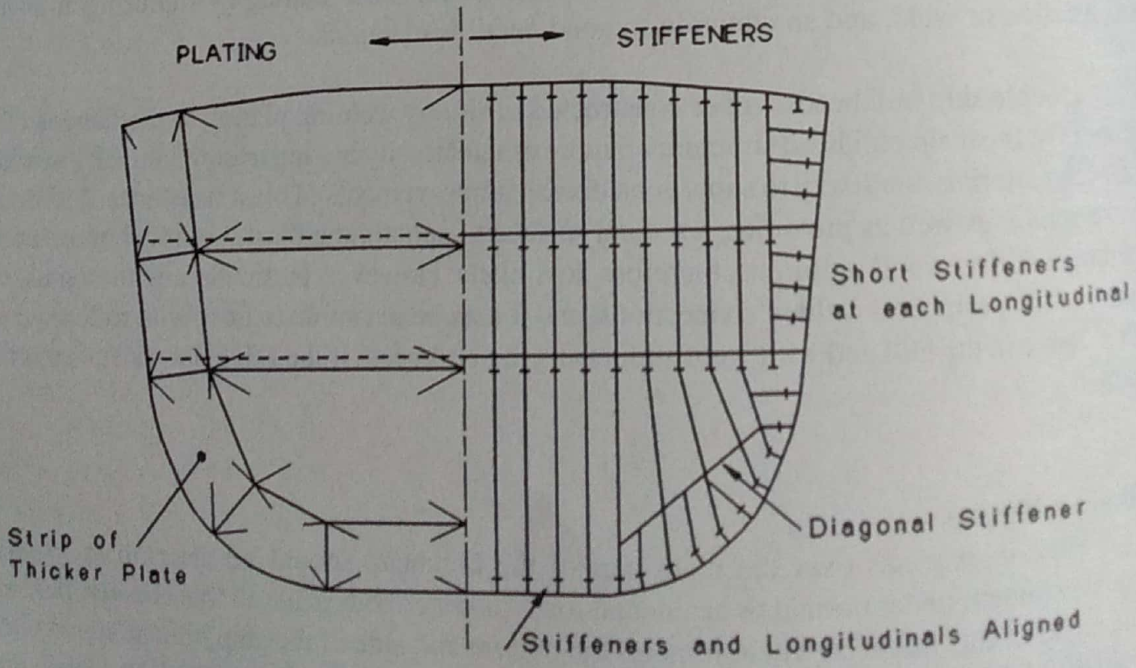
PLATING
STIFFENERS
Short Stiffeners at each Longitudinal
Diagonal Stiffener
Strip of Thicker Plate
Stiffeners and Longitudinals Aligned

Figure 9.1 Explosive Resistant Bulkhead

important because, unless every longitudinal is 'backed up' by a bulkhead stiffener, the bulkhead plating may easily rupture under explosive attack. Bulkhead stiffeners in the peripheral zone should lie as nearly as possible at right angles to the hull plating.

b. Below the turn of bilge the requirements of (a) can generally be met by the normal system of bulkhead stiffening. At and above the turn of bilge, short stiffeners lying normal to the hull plating should be fitted at every longitudinal stiffener. These short stiffeners should extend at least to the inner edge of the thick plating described above (paragraph 49) and should end on a main bulkhead stiffener. A typical arrangement is shown in Figure 9.1, where it should be noted that all longitudinals above, as well as below, the waterline have supporting bulkhead stiffeners to withstand nuclear air blast as well as underwater attack.

c. To match each bulkhead stiffener to its adjacent longitudinal, the cross sectional area of the bulkhead stiffener at its outer end should desirably be not less than 60% of the cross sectional area of the *web* of the longitudinal. In way of deep longitudinals this may require a fairly heavy stiffener, in which case the area may be achieved by adding a short stiffener on the other side of the bulkhead, provided that the inboard end is snaped off at a slope not steeper than 1:4.

d. Where the above rules require a bulkhead stiffener to have greater scantlings at its outer end than are required for strength under lateral pressure, the sectional area may be tapered in accordance with the following formula:

$$A_x = 0.6\,A_L - 2tx/3 \qquad (9.6)$$

where A_x is the sectional area of the stiffener at distance x from its outer end and will not, in general, be less than the normal bulkhead stiffener cross sectional area;

A_L is the web area of the adjacent longitudinal;

and t is the bulkhead plating thickness at x.

e. The function of the bulkhead in withstanding water pressure must not be forgotten when deciding the arrangement of stiffeners. The requirements of (a) to (d) above usually lead to diagonal stiffeners in way of the lower part of the turn of bilge as shown in *Figure 9.1*. Each end of this diagonal should terminate on a stiffener which runs *straight* between a longitudinal and lowest deck. These two stiffeners at the end of the diagonal must have sufficient bending strength to resist the forces transmitted to them by the diagonal stiffener as well as the forces associated with lateral pressure applied to the plating.

Structural Details

52 Bulkheads should be all-welded and intermittent welding should be avoided. All stiffeners should be of symmetrical section because any eccentricity is an addition and avoidable source of weakness.

53 Where a longitudinal pierces a bulkhead the filling collar may be either lap or flush welded except at a deep longitudinal or the keel where flush welding is essential.

54 Bulkhead plating should be welded directly to the shell plating and deck; a lap welded boundary bar presents an undesirable weakness. On the other hand the 'hard line' where the bulkhead abuts the shell is not a particular source of weakness and a boundary bar on the shell is unnecessary. If such a bar is fitted for some other reason, its thickness should not exceed two thirds of that of the shell plating and its total width be not less than 10 times its thickness.

55 The structural arrangements in way of holes in bulkheads should be in accordance with the design specification and will need careful consideration as discussed in Chapter 12. They should be sited as far from the edge of the bulkhead as possible, and reinforced so as to keep stress concentrations to a minimum.

Other Design Considerations

56 Near the stern, and especially in the region above the propeller, it will be necessary to check the vibratory characteristics of the bulkhead in accordance with the guidelines in Chapter 14. In particular, plate and grillage resonant frequencies within 20% of any common operational shaft or blade rate should be avoided.

57 Special consideration may need to be given to the integrity of large penetrations such as watertight doors or shaft glands to ensure that bulkhead deflections under normal loading or after damage do not impair the operation or the watertightness of the item. Extra stiffening may be necessary in these areas.